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Development of a Doctor's Finger Motion Measurement Device for a Remote Catheter Operating System

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Abstract **– Minimally invasive surgery is expected to become increasingly popular in medical practice, both for diagnosis and for surgery. However, there are some problems. For example, doctor's hands and faces are exposed to X-rays during an operation. To solve these problems, researches of robotic systems for minimally invasive surgery assistant have been carried out widely. The purpose of this paper is to develop the method of control for a remote catheter system with doctor's finger motion measurement device. The catheter insertion was measured using the acceleration sensor and the catheter rotation was measured using the flex sensor. We carried out the experiments which showed the insertion operation between the novel device and the slave side which was developed in our lab. The above results verified the effectiveness of new methods for the slave side control.**

Keyword: Minimally invasive surgery, Master-slave catheter operating system, Acceleration sensor, Flex sensor.

I. INTRODUCTION

In recent years, there are more and more people who choose minimally invasive surgery because of the high rate of procedural success and other various advantages. The advantages are the short duration of hospitalization and a small operative scar when compared with the conventional method. Use of X-rays is mentioned as one of the problems of the existing low invasion medical treatment. X-rays are used to acquire the position information on the catheter inside a patient's body. During operations, in order to reduce the exposure X-rays, doctors wear protecting suits, but it is very difficult to protect doctors' hands and face from the radiation of the X-ray. A patient's body, doctor's hands and face are exposed to X-rays during an operation. A patient's exposure can be managed minimized, but since doctors must perform many operations, doctors are anxious about cumulative exposure. In addition, there are dangers of mingling or breaking the blood vessels. In order to solve the problem, the communication technique using the Internet is used and the remote catheter system which can undergo an operation distantly is proposed. Robotic system have many advantages, like higher precision and can be controlled remotely, etc. However, compared with the hands of human being, none of the current robotic system can satisfy all of the requirements of a minimally invasive surgery. Not only because the machine is not as flexible as human hands, but also lacks the sense of touch. In any case, robotic catheter manipulation systems could provide assistance to surgeons in the operation room, but it has a long way to go to replace human being. A lot of products and researches are reported in this area. One of the popular products is a robotic catheter placement system called Sensei Robotic Catheter System supplied by Hansen Medical [1-3]. The Sensei system provides the physician with more stability and more force in catheter placement with the Artisan sheath compared to manual techniques, allowing for more precise manipulation with less radiation exposure to the doctor, and is commensurate with higher procedural complications to the patient. Because of the sheath's multiple degrees of freedom, force detection at the distal tip is very hard. Catheter Robotics Inc. has developed a remote catheter system called Amigo [4]. This system has a robotic sheath to steer the catheter which is controlled at a nearby work station, in a manner similar to the Sensei system. The first human trail of this system was in April 2010 in Leicester UK, where it was used to ablate atrial flutter. Magnatecs Inc. produced their 'Catheter Guidance Control and Imaging' (CGCI) system [5]. This system has 4 large magnets placed around the table, with customised catheters containing magnets in the tips. The catheter is moved by the magnetic fields and is controlled at a nearby work station that the Stereotaxis Inc. developed as a magnetic navigation system: the Stereotaxis Niobe [6]. The system facilitates precise vector based navigation of magnetically-enabled guide wires for percutaneous coronary intervention (PCI) by using two permanent magnets located on opposite sides of the patients table to produce a controllable magnetic field. These products are composed of two parts. One of the two is the master side which is surgeon console. The another one is a slave side, which is the catheter manipulating system .However, these products' method differ greatly from conventional surgecal method. It takes a long time to become skilled at controlling the master side. In this paper, we discuss a method we developed to allow the master side to control the slave side. The master side is the glove incorporating sensors. The glove is used to measure the catheter's insertion and rotation. The advantage of this method is to use a clinic catheter. It causes that a doctor's experience can be used. Therefore the person who is poor at mechanical control could immediately begin using this device. This way, the master side allows control of slave side in a way that is very similar to the conventional method. As a result, the novel method can control the slave side. From our results, we can conclude that the novel method to control the slave side is a promising method in the surgical console of the slave side. The paper is organized as follows. In section II, the design of the device will be described. Section III presents the methods of measuring the insertion operation and rotation operation. Section IV shows the experimental results of the control slave side for insertion operation. In section V, conclusions are given.

II. STRUCTURE DESIGN

A. The measurement method of insertion operation

Based on the component are described in Section I, a prototype of the master side using the glove incorporating sensors which include acceleration sensor and flex sensor, is developed and verified by experiment results. The prototype of master side is shown in Figure 1. The acceleration sensor is fixed at thumb to measure insertion operation of a catheter. On the other hand, flex sensor is fixed on the middle finger to measure rotation operation of a catheter. Insertion operation is repetitive motion. We assume that the acceleration of the repetitive motion is measured by the acceleration sensor. Then we can calculate the amount of the displacement by using equation (1).

$$\iint adt = \int vdt = d \tag{1}$$

Where a, v, and d are acceleration, velocity, displacement, respectively.

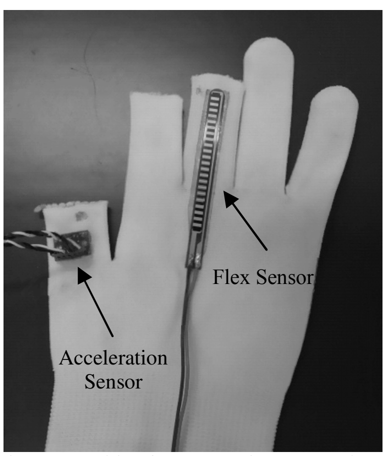


Fig.1 The master side of remote catheter operating system

There is a problem on the measurement of insert operations using the acceleration sensor. The problem is that the error of the sensor is amplified by the integrator. Therefore, in this paper, in order to reduce the dynamic variation of the offset error of the acceleration sensor from the raw data converted A / D, the value of the dynamic offset is overwritten by using the following algorithm.

$$\left(Volt - V_0\right)^2 > D_1 \tag{2}$$

Where volt, V_0, and D_1 are the output voltage of the acceleration sensor, the value of the offset and threshold value. If the left side value does not exceed D_1 during 0.5 seconds, an offset is updated with the change of the current output voltage. Conversely, when following equation is met, the voltage isn't a variation of offset. It will be detected as acceleration.

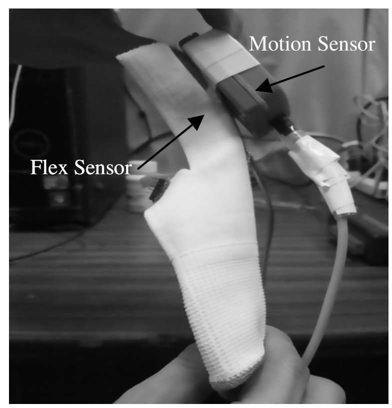
$$\left(Volt - V_0\right)^2 > D_2 \tag{3}$$

Where D_2 is threshold value.

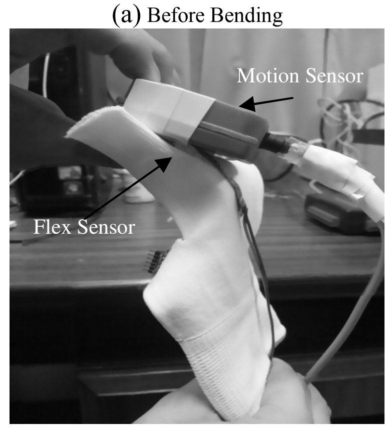
When the equation (3) is met, the amount of movement is calculated by the double integration.

B. The measurement method of rotation operation

Rotation operation of the catheter is measured by flex sensor. Flex sensor is attached to the position of the 2nd joint of the middle finger, and used to measure the bend angle. The output of the flex sensor is resistance which is in proportion to a bend angle. However, there is no equation that shows the relationship between the sensor output value and the bending angle. Therefore, it is necessary to determine the relationship of the sensor output value and the bending angle of the second joint. The calibration which calculates the equation of the relation of the voltage and the bend angle was performed by a motion sensor, a flex sensor, and an A/D converter. Fig.2 shows the experiment of calibration.



(a) Before Bending



(b) After Bending

Fig.2 Simulation of the finger motion

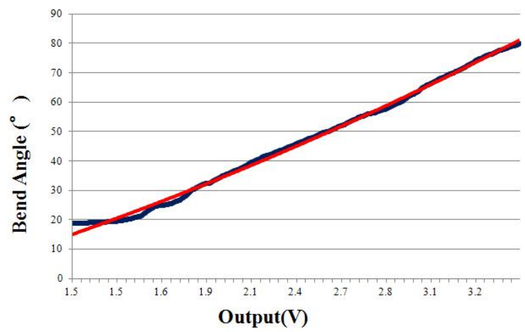


Fig.3 Result of calibration

The data shown in Fig.3 was obtained from calibration. Black line and red line (in the figure) shows bend angle – output voltage curve and approximate curve. By analysing the curve based on the MATLAB, equation of the relation between output voltage and a bend angle can be calculated. The equation is as following.

$$\theta = 3.121x^2 + 15.45x - 9.498 \qquad (2)$$

Where θ is the bending angle of the second joint of the middle finger and x is the output voltage of the sensor. Fig.2(b) shows the model of the rotation operation .

In order to calculate the amount of rotations of a catheter from the data of the bend angle, the equation which calculates the amount of rotations was formed in this condition.

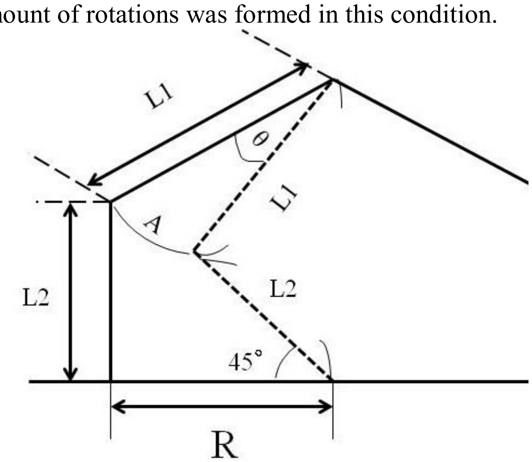


Fig.4 The model of the rotational movement

In Figure.4, the broken line, A, L1, L2, R, and θ represent the finger after movement, and arc is drawn by L1,length from the 1st joint to the 2nd joint, length from the fingertip of the middle finger to the first joint, amount of rotations, and bending angle of the finger's second joint. Because first joint of the fingers can't move independently, A and R are in proportional relation. A can be calculated using the following equation as:

$$A = L1 * 2\pi * \theta / 360 \qquad (3)$$

Because X and Y are in proportional relation, it can be derived the following equation:

$$R = K\theta \qquad (4)$$

Where K is a proportionality factor. After determining the bending angle by flex sensor, calculate the bending angle using equation (4).

III. EXPERIMENTAL SETUP

A. The slave side control experiment (insertion operation)

The control system of slave side that has been developed in our laboratory using the master system proposed in this paper, and we evaluated its characteristics. The experimental system is composed of sensor gloves, simulator EVE surgery, real catheter, and the slave side. Figure 5 shows the system configuration of the experiment. The slave machine is moved by acceleration sensor's output.

Fig.5 Experimental Set up of slave side control experiment

In this experiment, the slave side was controlled by the sensor glove. And insertion operation was performed under the same condition as the actual surgery. The fig.6 shows the condition of the slave side control experiment. (a) shows the initial state of experiment. (b),(c),(d),(e)and(f) show the state in respective times.

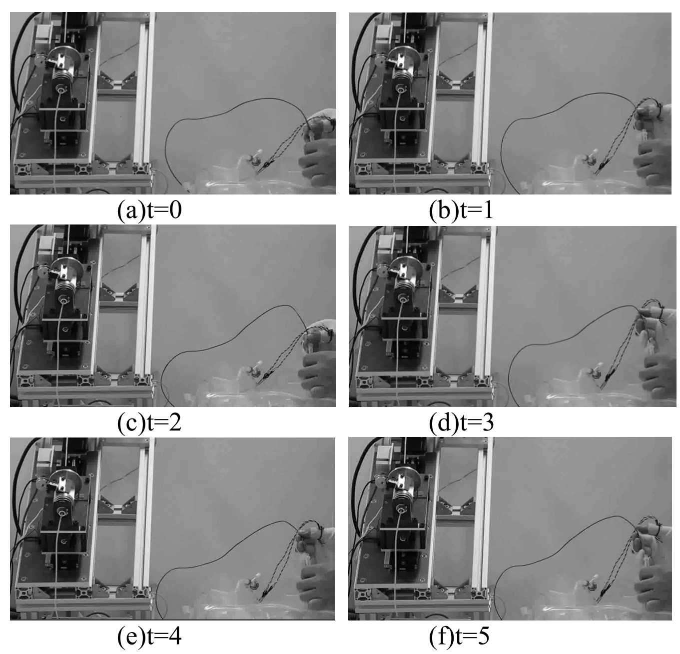


Fig.6 Experiments of the slave side control experiment

B. The experiment of rotation operation by using the encoder

The experimental system consists of flex sensor, real catheter, and encoder. This experiment was carried out for compare with encoder's output and Flex sensor's output. Figure 7 shows the actual state. Real catheter is laced the encoder. When it is rotated, two kinds of data were obtained from the flex sensor and encoder, at the same time.

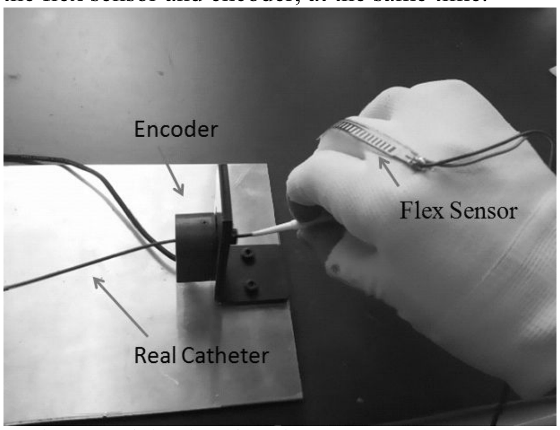


Fig.7 Actual situation of rotation measurement experiment

IV. EXPERIMENTAL RESULTS

A. The experimental result of slave side control

Figure.8 shows the results of the slave control experiment. This figure shows the superimposed data of output voltage of the acceleration sensor and position data from the encoder which is coupled with the motor were obtained from the slave side at the same time. This black line in the figure 8 shows output voltage from the acceleration sensor, and the blue line represents the amount of movement of the stage from the encoder. Curve of the output voltage from the acceleration sensor is not a smooth curve due to the fact that it contains the error. However, the position information of the slave side is a smooth curve by using an algorithm to reduce the error

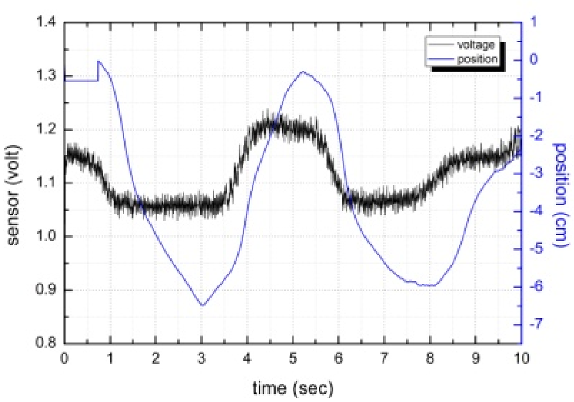


Fig.8 Experimental result of slave side control experiment

B. The experimental result of rotation operation

Figure.9 shows data from the flex sensor which is converted to a bend angle based on the equation 2 and 4 of the bending voltage. The rotation angle is a relative angle based on the initial state. Therefore, the maximum value of the wave represents the amount of rotation of each single operation. Figure.10 shows data from the encoder. The rotation angle is an absolute angle. From the results (Fig.9 and Fig.10), comparing the results of two experiments, we found that our measurement method of rotation operation is useful.

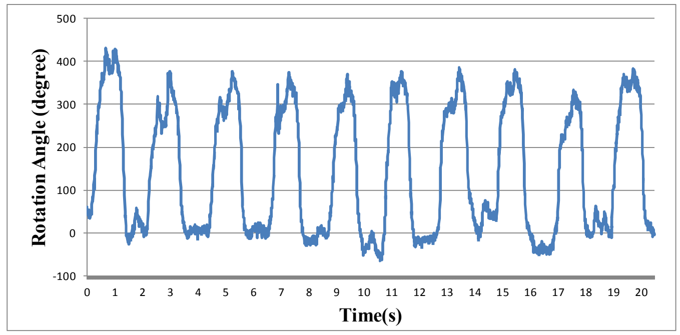


Fig.9 Experimental results of rotation measurement

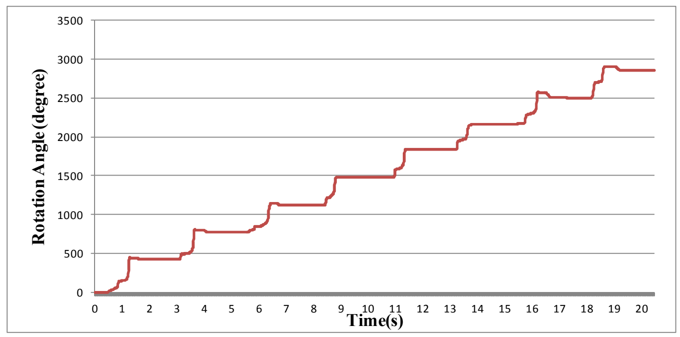


Fig.10 Experimental results of rotation measurement

V. CONCLUSIONS

The remote catheter operating system can be realized with appropriate signal processing techniques to reduce noises of the acceleration sensor. Using the sensor glove, we have achieved the control of the slave side and established a method to measure the rotational motion. As for the realization of the insertion operation with the acceleration sensor, there is a little different from the actual operation. It is necessary to improve it further. Also, in the future, our works will focus on the control of slave side for rotation operation.

VI. ACKNOWLEDGE

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